AFRL-RX-TY-TP-2011-0001

SIMPLIFIED METHODS FOR IMPROVING THE BLAST RESISTANCE OF COLD-FORMED STEEL WALLS

Bryan T. Bewick
Airbase Technologies Division
Air Force Research Laboratory
139 Barnes Drive, Suite 2
Tyndall Air Force Base, FL 32403-5323

Casey G. O'Laughlin
Jacobs Technology
Tyndall Air Force Base, FL 32403
Contract No. FA8650-09-C-0032

Eric B. Williamson
Universal Technology Corp
1 University Station -- C1748
Austin, TX 78712
Contract No. FA8650-07-D-5800-0054

JANUARY 2011

AIR FORCE RESEARCH LABORATORY
MATERIALS AND MANUFACTURING DIRECTORATE

■ **Air Force Materiel Command** ■ **United States Air Force** ■ **Tyndall Air Force Base, FL 32403-5323**

REPORT DOCUMENTATION PAGE	Form Approved OMB No. 0704-0188

The public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing the burden, to Department of Defense, Washington Headquarters Services, Directorate for Information Operations and Reports (0704-0188), 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to any penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.

PLEASE DO NOT RETURN YOUR FORM TO THE ABOVE ADDRESS.

1. REPORT DATE *(DD-MM-YYYY)*	2. REPORT TYPE	3. DATES COVERED *(From - To)*
01-JAN-2011	Conference Proceedings	01-JAN-2009 -- 01-JAN-2011

4. TITLE AND SUBTITLE
Simplified Methods for Improving the Blast Resistance of Cold-Formed Steel Walls (PREPRINT)

5a. CONTRACT NUMBER FA4819-09-C-0032

5b. GRANT NUMBER N/A

5c. PROGRAM ELEMENT NUMBER 62102F

6. AUTHOR(S)
*Bewick, Bryan T.; **O'Laughlin, Casey G.; Williamson, Eric B.

5d. PROJECT NUMBER 4918

5e. TASK NUMBER C1

5f. WORK UNIT NUMBER QF101013

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
**Jacobs Technology, 139 Barnes Drive, Suite 2, Tyndall Air Force Base, FL 32403
Universal Technology Corp, 139 Barnes Drive, Suite 2, Tyndall Air Force Base, FL 32403

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
*Air Force Research Laboratory
Materials and Manufacturing Directorate
Airbase Technologies Division
139 Barnes Drive, Suite 2
Tyndall Air Force Base, FL 32403-5323

10. SPONSOR/MONITOR'S ACRONYM(S) AFRL/RXQEM

11. SPONSOR/MONITOR'S REPORT NUMBER(S) AFRL-RX-TY-TP-2011-0001

12. DISTRIBUTION/AVAILABILITY STATEMENT
Distribution Statement A: Approved for public release; distribution unlimited.

13. SUPPLEMENTARY NOTES
Ref Public Affairs Case # 88ABW-2011-2523.
Submitted for presentation at the Project 2011 Conference, 30 Aug - 1 Sep 2011 in Lugano, Switzerland.

14. ABSTRACT
In recent years, cold-formed steel stud walls have become an attractive alternative to wood stud walls. Relative to wood, cold-formed steel is highly ductile, sustainable, and unaffected by insects, mold or rot. Research has demonstrated that cold-formed steel stud walls can perform well when subjected to large blast threats, but such performance has depended upon specially designed fasteners that are expensive to manufacture and require experienced workers to install properly. Despite the potential performance of these types of wall systems when specialized fasteners are used, current U.S. Department of Defense design guidelines for conventionally constructed steel stud walls use acceptability criteria that are much more conservative than wood stud walls due to the lack of data available. Thus, the goal of the current research effort is to develop techniques for mitigating large blast threats acting against steel stud walls using conventional construction methods and materials. The research includes controlled laboratory tests that are intended to identify the various failure mechanisms that can occur for different combinations of wall system parameters. Variables considered in the testing program include stud and track section properties, stud-to-track connection details, stud orientation and wall layout, and sheathing system properties. Based on the results obtained from the testing program and supporting analyses, the most promising wall system designs will be identified, and design guidance will be developed. Final designs will be tested under actual blast loads to verify performance and to ensure that wall systems behave as desired.

15. SUBJECT TERMS
steel stud walls, conventional connections, blast resistance, cold-formed steel studs

16. SECURITY CLASSIFICATION OF: a. REPORT	b. ABSTRACT	c. THIS PAGE	17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
U	U	U	UU	8	Christopher L. Genelin, Capt
					19b. TELEPHONE NUMBER *(Include area code)*

Standard Form 298 (Rev. 8/98)
Prescribed by ANSI Std. Z39.18

Simplified Methods for Improving the Blast Resistance of Cold-Formed Steel Walls

Bryan Bewick[1,a], Casey O'Laughlin[2,b], and Eric Williamson[3,c]

[1]Air Force Research Laboratory, Air Base Technologies Division, Engineering Mechanics and Explosive Effects Research Group, Tyndall AFB, FL, USA

[2]Jacobs Technology, Tyndall AFB, FL, USA

[3]University of Texas at Austin, Austin, TX, USA

[a]Bryan.Bewick@tyndall.af.mil, [b]casey.olaughlin.ctr@tyndall.af.mil, [c]ewilliamson@mail.utexas.edu

Keywords: Steel Stud Walls, Conventional Connections, Blast Resistance, Cold-Formed Steel Studs

Abstract

In recent years, cold-formed steel stud walls have become an attractive alternative to wood stud walls. Relative to wood, cold-formed steel is highly ductile, sustainable, and unaffected by insects, mold or rot. Research has demonstrated that cold-formed steel stud walls can perform well when subjected to large blast threats, but such performance has depended upon specially designed fasteners that are expensive to manufacture and require experienced workers to install properly. Despite the potential performance of these types of wall systems when specialized fasteners are used, current U.S. Department of Defense design guidelines for conventionally constructed steel stud walls use acceptability criteria that are much more conservative than wood stud walls due to the lack of data available. Thus, the goal of the current research effort is to develop techniques for mitigating large blast threats acting against steel stud walls using conventional construction methods and materials. The research includes controlled laboratory tests that are intended to identify the various failure mechanisms that can occur for different combinations of wall system parameters. Variables considered in the testing program include stud and track section properties, stud-to-track connection details, stud orientation and wall layout, and sheathing system properties. Based on the results obtained from the testing program and supporting analyses, the most promising wall system designs will be identified, and design guidance will be developed. Final designs will be tested under actual blast loads to verify performance and to ensure that wall systems behave as desired.

Introduction

Cold-formed steel stud walls have become a popular building material in United States Air Force facilities. By virtue of their material characteristics and properties, steel studs offer significant advantages over other materials such as wooden studs. Strength, ductility, and toughness offered by steel studs allow protection from blast loads also in addition to adherence to demanding wind and seismic building code requirements. Toughness offered by steel studs is significantly higher than brittle wooden studs due to the ductile behavior of steel. Toughness is defined as the area under a load versus deformation curve; toughness is also considered to be useful in quantifying the amount of energy absorption available for a given wall system. Other advantages of steel studs over wooden studs include the following: dimensional stability, a reduction in combustible material, and sustainability.

Of particular importance when designing structures to resist blast is the large amount of ductility offered by steel studs. When designed properly, steel stud walls can absorb energy from blasts through deformation; this energy absorption is a direct function of ductility. For steel stud walls to be effective in blast-resistant design, it is vital to prevent a premature failure at the connections before the studs can deform plastically and utilize their available ductility. Previous research by the Department of State (DOS), the Engineer Research and Development Center (ERDC) of the U.S. Army Corps of Engineers [1], and by the Air Force Research Laboratory (AFRL) [2,3] have shown that steel stud walls have significant potential for mitigating large blast events. These previous research programs [4,5] have investigated connection technologies that allow a full tensile membrane response of steel stud walls to blast. Issues with these connections, such as cost, installation time, and the required specialized design, make them an uneconomical solution for buildings that do not have to meet the highest blast-resistant design requirements. The goal of the current study is to characterize the blast resistance capabilities of conventional steel stud construction methods. Conventional screwed-stud-to-track connections in combination with common sheathing products such as oriented strand board (OSB) offer a level of blast resistance that may be effective in mitigating lower-level blast threats according to the standards established by the U.S. Department of Defense (DOD). In addition to screwed-type connections, commercial clips are also included in the research program to evaluate their effect on the overall performance of steel stud walls.

To date, research has not fully characterized the behavior of steel stud walls utilizing conventional construction methods responding to blast threats of different intensities. A gap in the research (Fig. 1) in the blast-resistance capabilities of steel studs has forced engineers to design either fully elastic or to the tensile membrane capacity.

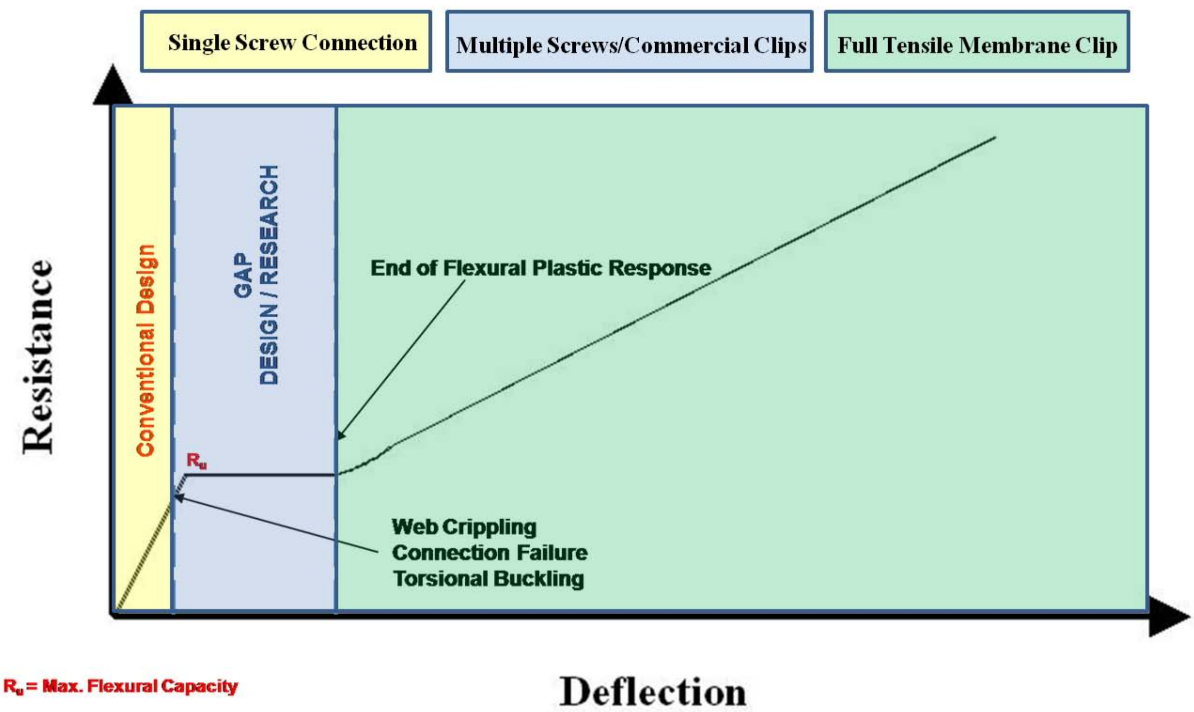

Fig. 1- Typical Steel Stud Resistance Function and Research Gap

For the design of steel stud walls to remain fully elastic, engineers must specify larger section sizes—resulting in higher costs associated with material and labor—than those required for other materials such as wooden studs. Also, if engineers elect to design into the full tensile membrane capacity region, full tension clip connectors are required. Incorporation of veneer layers into the resistance of steel stud wall systems has been disregarded in past design practice. Composite behavior between the veneers and the steel studs has not been considered to be a valid assumption; the laboratory test data presented in this paper indicate the apparent effect of veneers.

Therefore, characterization of conventional construction techniques will fill the ―gap" in research and potentially allow engineers to use steel stud construction to mitigate standard U.S. DOD blast threats. For the current effort, research activities focus on two main areas that have been identified as having potential to change the behavior of steel stud wall systems in a blast event:

1. Connection detailing associated with the standard screwed-stud-to-track connections and with commercial clips.
2. The mechanical interaction of veneer layers and steel studs and how those veneer layers affect the resistance of steel stud walls.

Objectives

Building from previous research, a main objective of the current study is to create an analytical methodology—validated against test data—that can accurately predict response limit states for various types of steel stud wall assemblies. Another objective is the development of a standard that will allow engineers to have the option of adding the increased resistance of veneer layers that can perform compositely with cold-formed steel studs, as the current standards do not account for the contribution made by veneer layers.

Primary factors in the selection of steel stud wall systems for use in U.S. Air Force facilities will be performance under blast loads, system cost, ease of construction, and availability of materials. Readily available materials and standard connection practices are considered in order to keep designs to a minimum cost. Standard sheathing materials such as OSB, gypsum and plywood— as well as specially selected sheathing products such as— Sureboard™, Densglass™, and light gauge sheet metal— are included in the experimental test program to determine the contribution of these veneer layers to the resistance of steel stud wall systems.

Scope

Through controlled laboratory testing, this research aims to characterize the failure modes of differing steel stud wall systems. Three component-level experiments investigate different failure modes that have been identified in past research [6] as being critical to the performance of steel stud walls: 1) tensile membrane action, 2) bending and prying action, and 3) crippling and crushing action. To understand wall system response, 2- and 3-stud wall configurations were tested statically in a load tree (Fig. 2) at the U.S. Air Force Research Laboratory at Tyndall AFB, Florida, U.S. Observations from these tests are being used to validate detailed finite element prediction models.

Ultimately, a validation experiment to a design-level blast event is planned to verify the accuracy of the prediction methodologies developed from this research.

Load Tree Tests

Although individual component tests help isolate different failure modes and identify parameters that limit capacity, it is important to understand how wall systems behave as a whole when each failure mode interacts with each other. It is also important to understand behavior of wall systems with different construction methods. For these reasons, testing wall systems in a “load tree” (Fig. 2) is a critical component of the experimental test program.

Fig. 2 - Load Tree Testing

A load tree is a test apparatus designed to apply a uniformly distributed load normal to the surface of the specimen; as the specimen deforms, the load points are free to reposition themselves in order to maintain spacing and continue applying load normal to the specimen surface. Such a setup closely approximates a pressure load acting on the wall, which is important for application to blast-resistant design. The load tree is ideal for developing the resistance functions to be used in single-degree-of-freedom analyses commonly used in blast-resistant design.

The load tree test matrix established for the current research program allows direct observation of wall system behavior with the presence of different kinds of sheathing, stud orientations, screw

patterns, and commercially available clip connectors. Sheathing materials such as gypsum and OSB are brittle and have significantly lower capacity than sheet steel. Nonetheless, data collected from load tree tests shows that the overall response of the system is more greatly affected by the presence of sheathing than by the strength of the sheathing materials used. ―LTT1:OSB/GYP" in Fig. 3 shows the effect of sheathing; an increase in flexural yield strength of roughly 400% over an unsheathed specimen is achieved by simply adding OSB and gypsum to the specimen. Though the materials themselves are brittle and have a lower strength than steel, they do offer enough strength to brace the steel studs laterally. Considering specimen ―LTT1: Unsheathed" from Fig. 3, which is a specimen without any sheathing, the studs begin to rotate laterally almost immediately as load is applied, and the flexural strength is significantly reduced because the studs are no longer bending about their strong axis. The OSB on the exterior face of the studs acts as a continuous brace for the bottom/compression flange of the studs and helps prevent rotation so that studs can utilize their strong-axis bending strength. Due to space considerations, this trend cannot be described for each specimen in this paper, but this behavior was observed throughout the test program. High quality sheathing materials such as sheet steel offer an even greater level of resistance relative to that offered by OSB, and such materials are useful in the design of steel stud walls that have to meet stringent blast-resistant design standards.

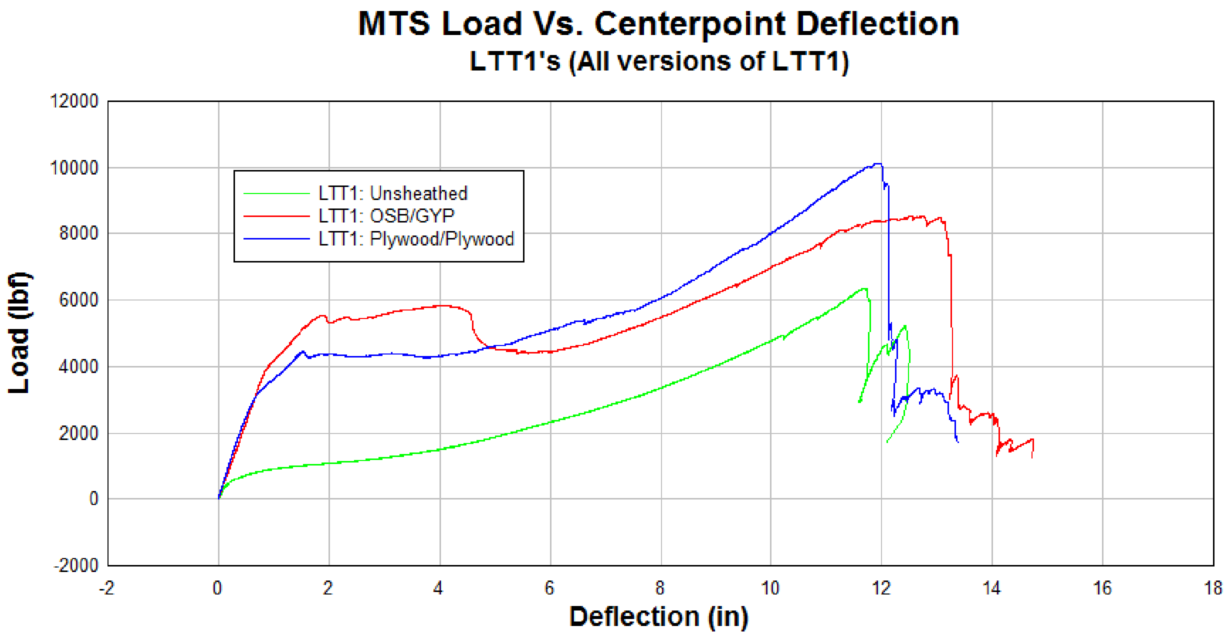

Fig. 3 – Effect of Sheathing on Resistance of Steel Stud Walls (Note the dramatic effect of sheathing.)

Most importantly, load tree testing allows for the observation of the governing failure mode when construction details of the stud wall are changed. Observations from load tree tests can be used in validating finite element models to ensure that they are capable of accurately predicting wall response and capturing the various sequences of component failures that can occur. The availability of such validated finite element models is essential for evaluating a wide array of different design options. Large-scale blast tests are costly and logistically difficult to carry out, and validated finite element models are used to understand wall system behavior and predict effects of modifications prior to carrying out such tests. Due to space limitations, details of the finite element modeling

effort are not included in the current paper, though additional information can be found in a forthcoming paper by the authors.

Summary and Conclusions

To address the gap in research of steel studs to threat levels less severe than those studied previously, three component-level test series were used to isolate failure modes known to be important in the response of steel stud walls subjected to blast loads. Component-level tests allow direct observation of failure modes associated with loading conditions when construction details are varied. Load tree tests have been designed to allow interaction of each failure mechanism, resulting in a more accurate representation of how an entire wall system is expected to behave under larger deformations than the component tests, and results from these tests are highly valuable. The results of each component-level test series and the load tree tests provide a basis for understanding how resistance available from steel stud walls change with different construction techniques. Also, test data have shown sheathing has a substantial effect on resistance of steel stud wall systems, and consideration should be given to changing current design methods to allow for composite wall behavior consideration.

Ultimately, this research program aims to show increased resistance of steel stud walls is possible by implementing simple enhancements to current conventional connection details and wall construction techniques, thus allowing designers to utilize steel stud walls to defeat or mitigate standard U.S. DOD threats.

References:

[1] DiPaolo, Beverly P. and Stanley C Woodson (2006). ―An Overview of Research at ERDC on Steel Stud Exterior Wall Systems Subjected to Severe Blast Loading.” *ASCE Structures Congress*, May 18-20, 2006, St. Louis, MO, USA.

[2] Salim, H., R. Dinan, and P. T. Townsend (2005). ―Analysis and Evaluation of In-Fill Steel-Stud Wall Systems under Blast Loading.” *J. of Structural Engineering*, ASCE, 131(8), 1216-1225.

[3] Salim, H., P. Muller, and R. Dinan (2005). ―Response of Conventional Steel Stud Wall Systems under Static and Dynamic Pressure.” *J. of Performance of Constructed Facilities*, ASCE, 19(4), 267-276.

[4] Dinan, R. (2005). ―Blast Resistant Steel Stud Wall Design.” Doctoral Dissertation, University of Missouri, Department of Civil Engineering, Columbia, MO 65211-2200.

[5] Shull, J. (2002). ―Steel Stud Retrofit Connection Development and Design.” Masters Thesis, University of Missouri, Department of Civil Engineering, Columbia, MO 65211-2200.

[6] Bewick, B., Hoemann, J., Williamson, E. (2010). ―Performance of Steel Stud Walls Subjected to Blast Loads.” *ASCE Structures Congress*, May 12-15, 2010, Orlando, FL, USA.